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TED On-Board: The U.S. Army's New Diagnostic Enabler

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TED On-Board: The U.S. Army's New Diagnostic Enabler

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Abstract

The U.S. Army is improving its logistic information systems so that it can continue to meet the logistics needs of future combat operations. This report describes a system that will provide engine status information on the M1A1 Abrams main battle tanks to battalion and brigade logistics maintainers. The system will reside on board the tank and is called TED On-Board. TED On-Board is an extension of a currently fielded (off-board) diagnostic system called TED (Turbine Engine Diagnostics).

Contents

1. Introduction	1
2. Turbine Engine Diagnostics	3
3. TED On-Board System	5
3.1 Objective	5
3.2 Hardware	5
3.3 Software	6
3.4 Benefits	7
3.5 Current Progress	8
4. Conclusions	12
References	13
Glossary	14
Distribution	17
Report Documentation Page	19

Figures

1. TED On-Board hardware configuration	6
2. Interface showing received message from TED On-Board	9
3. GRC ASA for Fort Hood demonstration	10
4. Sample data from Fort Knox test	11

1. Introduction

Advanced electronic and information technologies are converging in all areas of the marketplace. The U.S. Army has recognized the tremendous advances being made and is incorporating many of these technologies into its weapon systems to remain the most technically superior and sophisticated fighting force in the world. Turbine Engine Diagnostics (TED) On-Board (TOB) is one of several Army programs designed to bring Army logistics into the Information Age. Army logistics systems must be responsive to the fast pace of modern warfare. The Army's current logistics operations, however, are not adequate to support the continuous high-speed tempo of future combat operations. The phrases "sneaker net" and "swivel chair net" appropriately describe the state of Army logistics information systems at the brigade level and below.*

During tactical operations, logistics information flows in two directions: upward and downward. Platform status information moves from the weapon platform upward into the command and support systems. The command structure uses the data to determine factors such as combat readiness. The support structure uses the information to schedule needed maintenance or repair actions and to coordinate supply movements. The downward flow of logistics messages to the platform may contain status update requests or may provide notification of maintenance or supply activities.

As part of an effort to have a weapon system provide platform status information, an increasing number of recently developed systems have required various levels of built-in test and diagnostics equipment to decrease the reliance on general-purpose test equipment. Unfortunately, until now, the Army has not instituted any system, policy, or standards to guide materiel developers to an effective embedded diagnostics program.

In July 1997 representatives from the Army Materiel Command (AMC), Deputy Chief of Staff for Logistics (DCSLOG), Deputy Chief of Staff for Operations and Plans (DCSOPS), Assistant Secretary of the Army, Research Development and Acquisition (ASARDA), and Training and Doctrine Command (TRADOC) directed that the Program Manager for Test, Measurement, and Diagnostic Equipment (PM-TMDE) develop an Army-wide strategy for emplacing and embedding diagnostics on all Army equipment [1]. This directive resulted in the Army Diagnostic Improvement Program (ADIP) Master Plan. By April 1998, the Department of the Army (DA) stated that "embedded diagnostics and prognostics are tenants of Army XXI and the Army After Next" [2]. It directed that this become a requirement within

*"Sneaker set" refers to the methods of transferring information between computers at different echelons by manually carrying floppy disks. "Swivel chair net" refers to the method of transferring information between computers at the same echelon by retying information from one computer to another computer.

every Operational Requirements Document, that program managers (PMs) include embedded diagnostics on all new and retrofit equipment, and that they coordinate this action with PM-TMDE [1]. The Army Acquisition Executive also directed that embedded diagnostics become part of the PM's acquisition strategy and that it be coordinated with PM-TMDE [3].

2. Turbine Engine Diagnostics

Long before ADIP was proposed, the Ordnance Center and School (OC&S), in coordination with the U.S. Army Research Laboratory (ARL), took the Army into the world of digitized diagnostics. Shortly after the Gulf War, it became apparent that the M1A1 Abrams main battle tank, albeit the epitome of lethality and survivability on today's battlefield, is expensive to operate, support, and maintain. With the downsizing of the Army, experienced mechanics are quickly vanishing, along with their expertise. This, coupled with the rising costs of replacement parts and fuel, dictated the need for action if the Army was going to keep the M1A1 operational in the years to come. Since parts and fuel are dictated by the economy, the OC&S and ARL proposed focusing on the repair costs. Together, they developed the expert system TED to help the M1A1 tank's mechanic diagnose and repair the M1A1 tank's engine and transmission.

The development of the system began in 1991, and by 1994, TED was fielded for testing to the National Guard. The National Guard continued to incrementally field TED, and by 1996, the Army began fielding TED to all direct support (DS) units.

TED is a combination of hardware and software that together create a powerful diagnostic tool for all levels of mechanics who maintain and repair the M1A1 Abrams main battle tank. The hardware consists of a piece of diagnostic equipment called an **automated** breakout box (AOB). The software consists of a number of expert modules that are accessible to the mechanic through a menu-driven interface. To use TED as a diagnostic aid, the mechanic would need an AOB, a laptop, and the TED software.

Mark Kregal from ARL developed the AOB, which is an extension of the standard issue breakout box (BOB). His main purpose was not to add unnecessary specialized equipment to the mechanic's inventory. Hence, the AOB has all the same functionality as the original BOB with the additional feature of reading the electronic control unit's (ECU's) signals in a fraction of a second, digitizing them, and passing them on to the TED software for interpretation.

The TED software is divided into three main modules: TED, AOB, and RPSTL (repair parts and special tools list). The TED module separates the troubleshooting and maintenance routines into three specific areas: inspections, operational checks, and maintenance. The AOB module provides the mechanic an interface to the AOB by automating the manual tasks associated with the BOB and by providing instantaneous access to all the engine's voltage signals. The **AOB software** automatically monitors the voltage signals, and when a fault occurs, the mechanic is notified of the problem through the on-screen interface. The RPSTL module provides the

mechanic access to the extensive parts ordering information for the Abrams engine and transmission.

As a follow-on to the TED program, ARL, with the support of the U.S. Army Combined Arms Support Command (CASCOM), has developed a diagnostic enabler and embedded it on board the tank. This diagnostic enabler, hereon known as TED On-Board, is based on the automatic diagnostic capability found in TED.

CASCOM has been a strong supporter of the TED program, promoting it as the Army's first true interactive electronic technical manual (IETM). When ARL expressed the desire to bring the automatic diagnostic capabilities of TED on board the tank, CASCOM was quick to support and promote the program, using TED On-Board as an example of a retrofitted on-board IETM in the Capstone Requirements Document for the ADIP.

3. TED On-Board System

3.1 Objective

The goal of embedding a diagnostic system on board a weapon system is to perform diagnostics on the move and report the results to logistics personnel. With these goals met, the Army would realize a decrease in repair-cycle time, an increase in combat readiness, and a reduction in operation and support costs.

ARL has long had the desire to collect operational data from the tank so as to perform more accurate diagnostics. The data obtained on board the tank as it performs in varying conditions and environments will help identify and track trends of operational behavior, paving the way for prognostics.

The TED On-Board system continuously monitors all 32 signals from the engine and reports failures as they occur. In addition, periodic health checks can be performed automatically as operational conditions warrant. This action will differentiate and expedite repairs.

The onboard system must communicate the information obtained from the engine to tank crew, operators, commanders, and logistics personnel. TED On-Board will use a small one-line liquid crystal display (LCD) to immediately inform the crew and operator of potentially dangerous faults. In addition, it will link directly to the Force XXI Battle, Command, Brigade, and Below (FBCB2) system, where available, or to the tank's Single-Channel Ground and Airborne Radio System (SINCGARS) via a serial cable connection. The interface between the onboard system and the FBCB2 or radio enables the vehicle to transfer the engine's condition to other tanks and key logistics personnel.

3.2 Hardware

The challenges facing ARL in incorporating TED's capability on board the tank required the system to be compact, rugged, and efficient. The confines of the tank dictated that the footprint for the TED On-Board be much smaller than that of the original ABOB. Power constraints further restricted the system to be a low-load unit that can operate on tank voltage. Maintaining compatibility with all M1 tanks, the system uses SINCGARS, the communications system common to the entire fleet of M1 tanks, to communicate off the tank.

To meet these challenges, ARL chose a PC/104 bus architecture. The PC/104 bus architecture provides all the advantages of the PC architecture in a small rugged package, with minimized power consumption and heat dissipation. The PC/104 boards are small (3.6 in. \times 3.8 in.) and contain self-

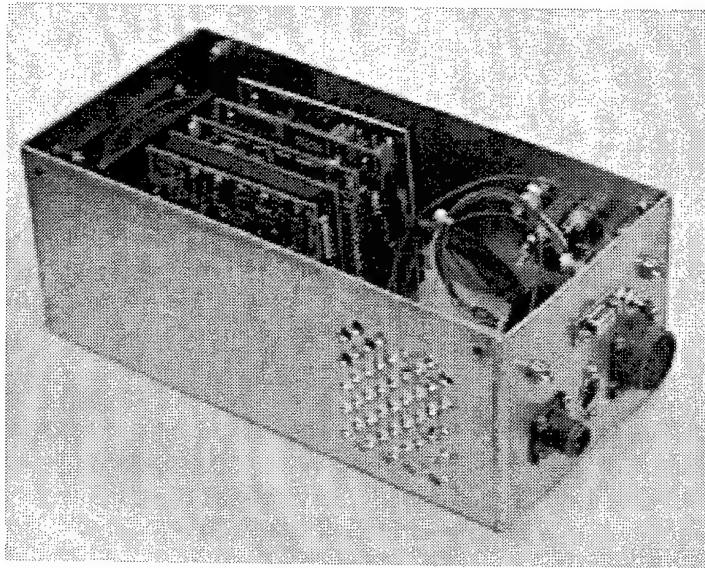
stacking connectors to allow multiple boards to be mounted in a low-profile design just 0.6 in. apart. The solid pin-and-socket connectors make the PC/104 architecture significantly more rugged than its competitive embedded PC options. The PC/104 signals have a reduced bus drive, only 4 mA, resulting in minimal power consumption and heat dissipation.

PC/104 boards have been an open standard since 1992 and have been successfully used in many commercial applications, including space-constrained vehicular, mobile, and avionics systems. In addition, a wide number of PC/104 CPU configurations are available. A 486 DX processor with a keyboard input, two RS232 communication ports, and a parallel port was chosen for the four TED On-Board prototypes that ARL currently has. An analog-to-digital (A/D) board, along with the multiplexer board used in the ABOB, provides the capability of obtaining the analog signals from the standard 128-pin connector and converting them to digital for use by the system. A video graphics adapter (VGA) board was added to the system, as well as a 2.1-GB hard drive to facilitate debugging. Finally, a power supply that can use input voltage from 6 to 30 V was used to power the system. The final configuration is shown in figure 1.

3.3 Software

To conserve power, reduce complexity, and lower costs, most embedded systems use a rudimentary operating system such as DOS. In the long term, TED On-Board will also use a similar type of operating system. ARL decided that the quickest, most economical way to develop the TED On-Board software was to start with a proven product, TED, and adapt it to meet the needs of an onboard system. The automated diagnostic software in TED is written in Inprise's DELPHI, a Windows-based object Pascal language. Therefore, in the near term, the TED On-Board software was built and runs in the Windows operating environment.

Figure 1. TED On-Board hardware configuration.



The Windows operating environment affords many advantages in building a system that the DOS environment lacks. The first and most obvious is a well-defined and easily understood user interface. Although not important for the final onboard system since it will contain no visual interaction with the user, Windows is vital in the development process to help fix problems and refinement.

The ABOB software monitors the 32 signals coming from the ECU until a fault has been detected. At this point, the user is notified and the system stops looking for out-of-tolerance data. In contrast, an onboard system needs to continue monitoring engine signals even after a fault is discovered. It must know how to interpret one fault while continuing to monitor for other faults. TED On-Board expands the ABOB software to incorporate this capability.

In the final configuration, the TED On-Board system will continually monitor all 32 signals from the engine, reporting faults as they occur. When a fault is detected, the system determines which subsystem is affected and the possible tools and components needed to repair it. The system combines all this information into a message that is sent off board to all appropriate personnel through the radio interface.

3.4 Benefits

The benefits associated with such a system, especially when it is linked to an integrated maintenance management system, include increased combat readiness, decreased operation and support (O&S) costs, and the ability to anticipate maintenance needs.

TED On-Board will increase combat readiness by keeping the tank crew, tank commander, and logistics personnel informed about the operational status of the tank. TED On-Board provides commanders with an accurate assessment of their equipment at all times, allowing them to establish priorities and immediately marshal the exact resources needed to maintain a high level of combat readiness. The system does this through the reporting of out-of-tolerance engine data as well as engine health check data to all levels of command using the FBCB2 system. This knowledge becomes especially important during offensive operations because it will permit *fixing on the move*, as opposed to the former practice of leaving disabled equipment until supporting maintenance elements respond.

O&S cost savings are discovered through improving system diagnostics, reducing repair cycle time, eliminating expensive tools and test equipment, minimizing parts usage, monitoring engine health in real time, and maximizing the capabilities of maintenance personnel. Based on the same diagnostic algorithms found in TED, the TED On-Board system is expected to reduce the no-evidence-of-failure (NEOFF) rate by at least 50 percent, thus reducing the unnecessary use of parts and personnel. TED On-Board will decrease the repair cycle time by reporting failures as they occur to combat

service support (CSS) personnel. Onboard diagnosis eliminates the need for much of the off-board diagnostic equipment currently used. Real-time health monitoring performed by the system will track an engine's performance, and as it declines, the system will request routine maintenance to prevent a catastrophic failure from occurring.

The TED On-Board link to the Global Combat Support System Army (GCSS-A) will provide an integrated CSS solution that especially leverages relevant CSS functions. Armed with the information from the onboard diagnostics, the logistics manager can order and direct maintenance assets to most effectively and efficiently fulfill the mission. The result is anticipatory logistics.

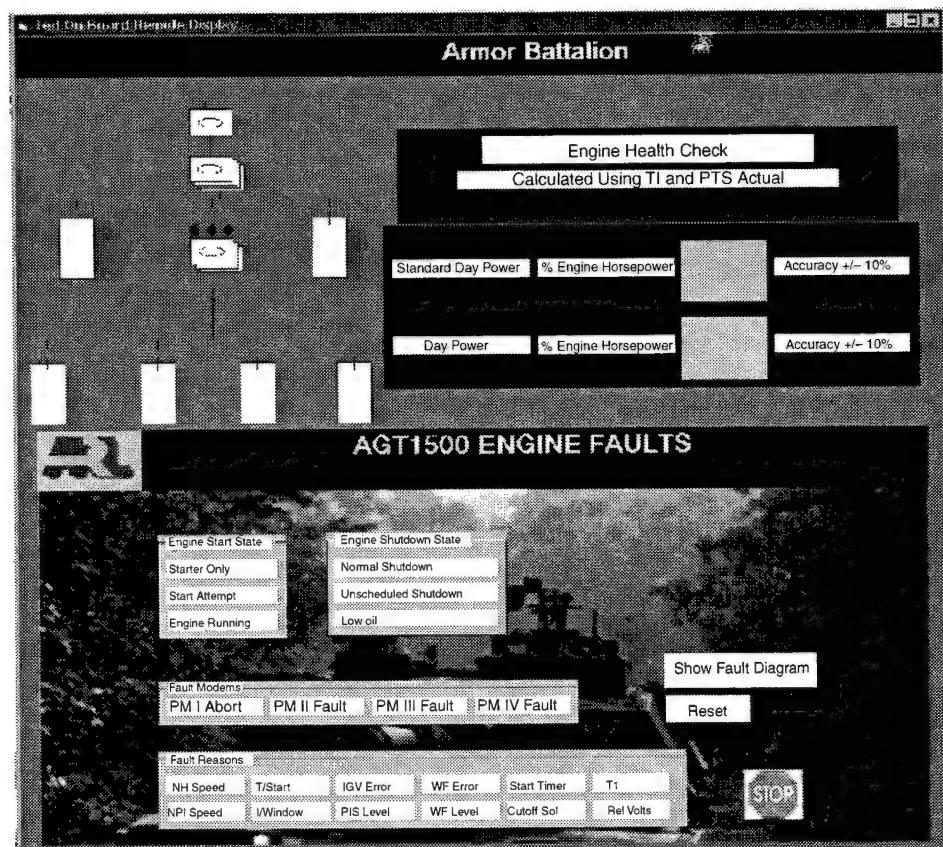
3.5 Current Progress

The communications portion of the TED On-Board system was demonstrated at the annual Federated Laboratory Symposium at the University of Maryland, College Park, campus in February 1999. The demonstration used the ARL prototype communications vehicle as the tactical operations center (TOC), located at the College Park campus, and a full-up power pack (FUPP), located approximately 4 miles away at the ARL-ALC headquarters. A software program developed by ARL to visualize the TED On-Board data was downloaded on a PC in the communications vehicle and received data via the onboard SINCGARS radio. The TED On-Board system was linked to the FUPP and broadcasted the diagnostic data via a SINCGARS radio to the communications vehicle at College Park. This same scenario was used for a congressional demonstration given at ARL-ALC in March 1999. The only difference was that the communications vehicle and the FUPP were colocated at the ARL-ALC compound.

ARL demonstrated the diagnostic and communication capabilities of the TED On-Board system in March 1999 at Aberdeen Proving Ground (APG), MD. The TED On-Board prototype was temporarily mounted in an M1A2 tank and linked to the ECU and to the tank's SINCGARS. A tent, under which another SINCGARS was connected to a laptop, was set up to represent a command post. The laptop was loaded with a software program developed by ARL to receive and display the diagnostic information sent by the TED On-Board system. The test consisted of starting and running the tank, inducing a fault on the fly, and communicating the diagnostic information from the tank to the command post over the SINCGARS with the use of a predetermined message format. Figure 2 is an example of the information received.

ARL has been working closely with General Research Corporation (GRC), the main contractor under the ACT II contract with the Army, to develop a standardized message format for embedded diagnostic systems. The message format must be flexible enough to support different types of diagnostic and maintenance information, must be portable (i.e., operating system

Figure 2. Interface showing received message from TED On-Board.



independent), and must be easily updated to accommodate changes in diagnostic equipment and Army maintenance doctrine. XML (Extensible Markup Language) is being considered for the message format because it is such a powerful tool for data representation, storage, modeling, and interoperation.* GRC, with input from ARL, has developed a document-type definition (DTD) for the TED On-Board data. A DTD is the validation specification, or grammar, for the language defined for data using the XML format. GRC built an Anticipatory Support Architecture (ASA) for use at a forward support company to receive and assess embedded diagnostic data from weapon system platforms using the XML format. In late July 1999, at APG, GRC demonstrated this architecture via an M1A2 tank equipped with a TED On-Board system as its data source. The TED On-Board correctly identified engine faults and communicated those faults to a simulated TOC equipped with the GRC ASA. The ASA received the engine fault data and identified the unit and vehicle affected.

After the July demonstration, GRC expanded the ASA to include recommendations of tasks, work orders, and repair parts required to sustain the weapon system in a mission-capable condition. These recommendations

*XML is actually a metalanguage that gives the power of representing the contextual meaning of data. These qualities of XML, in addition to it being a subset of SGML (the DoD standard format), make it a prime candidate for this application.

will then be forwarded to the battalion command and to GCSS-Army. This effort was demonstrated at APG in December 1999 with the use of the same configuration as the July demonstration. An additional demonstration occurred at Fort Hood, TX, in January 2000 with two M1A2 Abrams tanks equipped with TED On-Board systems. The demonstration was essentially the same as the December demonstration at APG, except for the additional tank. Figure 3 shows the ASA as it stood for the January demonstration. These demonstrations established that linking TED On-Board health checks and diagnostics to a prototype of the GCSS-Army is feasible, effective, efficient, and capable of achieving anticipatory logistics.

Of the four TED On-Board prototype systems, three were used in a prolonged field experiment at Fort Knox, KY, from June to December 1999. The fourth system remained at ARL, where it was used for further testing and demonstration. The experiment consisted of two separate tests: one conducted by PM Abrams and one conducted by CASCOM. Two of the TED On-Board systems were mounted on board M1A2 tanks involved in regular field exercises, with the third system available as backup. The PM's goal was to test the system for possible inclusion in the redesigned hull network box (HNB) for the M1A1. The PM was interested in the ruggedness of the system and the accuracy of the diagnostics. Figure 4 shows a sample of the data that were collected. Using TED On-Board as its data source, CASCOM was interested in testing the communications and database portions of GCSS-Army.

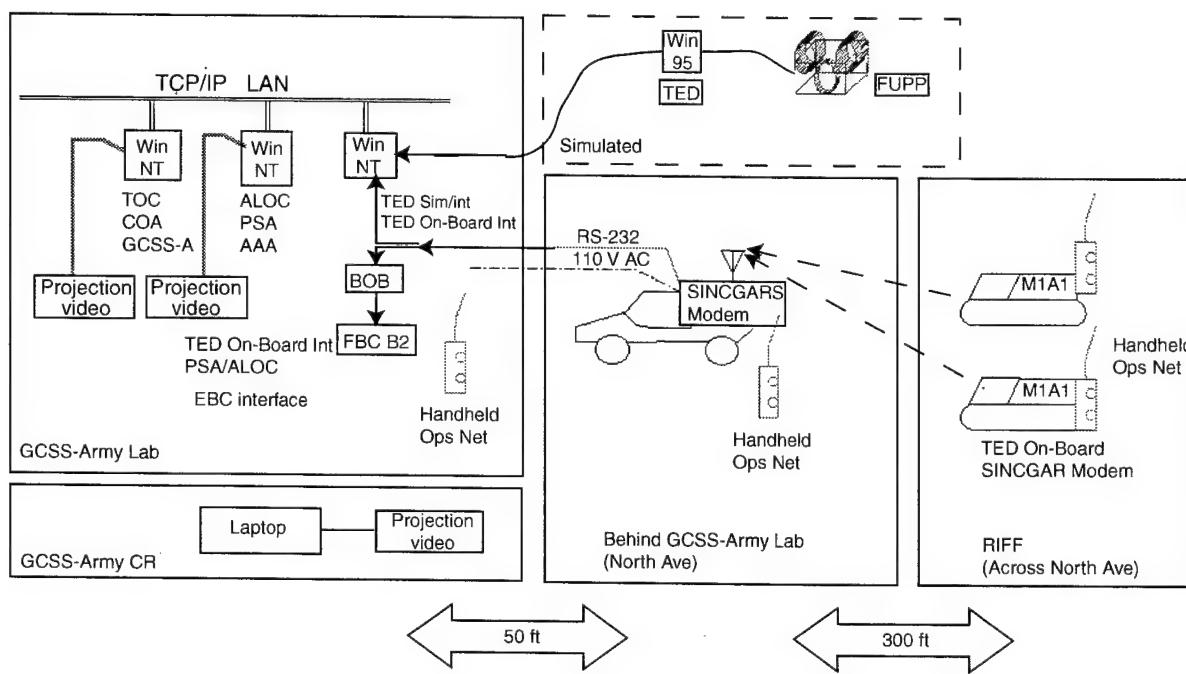


Figure 3. GRC ASA for Fort Hood demonstration.

Figure 4. Sample data from Fort Knox test.

```
***** TOB Version 08 ***** Jun 1999 ***** at: 6/22/99 7:13:53 AM
ECU ON at: 6/22/99 7:13:54 AM
ECU model = DECU at: 6/22/99 7:13:54 AM
Start Attempt at: 6/22/99 7:20:45 AM
Engine running at: 6/22/99 7:21:13 AM
Begin PM II Condition at: 6/22/99 7:22:50 AM
IGV Error: at: 6/22/99 7:22:50 AM
End PM II Condition at: 6/22/99 7:22:51 AM
Normal Shutdown at: 6/22/99 7:37:40 AM
Start Attempt at: 6/22/99 7:39:10 AM
Engine running at: 6/22/99 7:39:35 AM
Begin PM II Condition at: 6/22/99 7:42:28 AM
IGV Error: at: 6/22/99 7:42:28 AM
End PM II Condition at: 6/22/99 7:42:28 AM
Normal Shutdown at: 6/22/99 7:45:58 AM
***** TOB Version 08 ***** Jun 1999 ***** at: 6/22/99 8:44:32 AM
ECU ON at: 6/22/99 8:44:34 AM
ECU model = DECU at: 6/22/99 8:44:34 AM
Start Attempt at: 6/22/99 9:54:59 AM
Engine running at: 6/22/99 9:55:25 AM
Normal Shutdown at: 6/22/99 10:09:03 AM
```

4. Conclusions

The TED On-Board system prototype design is still too bulky to be used practically in the M1 fleet of vehicles. Ideally, the components of the TED On-Board system can be incorporated onto one card that can be added to the HNB. ARL contacted personnel from PM Abrams who are involved in designing the proposed new HNB. They were given a demonstration of the TED On-Board system in March 1999 and are in favor of incorporating the system into the new HNB.

ARL would like to expand the capabilities of TED On-Board to include other systems besides the engine and transmission. Expanding the hardware to read 128-pin data and incorporating the data into the HNB would give the system access to vital information such as fuel levels, oil pressure, etc. The capability of reading 128-pin data would also allow the system to connect to any Army vehicle system that contains a standard 128-pin connector. The final hurdle would be developing the diagnostic algorithms to interpret the signals received.

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2. DA memorandum, *Accelerated Application of Embedded Diagnostics*, 30 April 1998.
3. SA RD-SI memorandum, *Horizontal Technology Integration and Accelerated Application of Embedded Diagnostics on Army Equipment*, 8 June 1998.

Glossary

ABOB	automatic breakout box
A/D	analog to digital
ADIP	Army Diagnostic Improvement Plan
AMC	Army Materiel Command
APG	Aberdeen Proving Ground
ARL	Army Research Laboratory
ASA	Anticipatory Support Architecture
ASARDA	Assistant Secretary of the Army, Research Development and Acquisition
BOB	breakout box
CASCOM	Combined Arms Support Command
CSS	combat service support
DA	Department of the Army
DCSLOG	Deputy Chief of Staff for Logistics
DCSOPS	Deputy Chief of Staff for Operations
DS	direct support
DTD	document-type definition
ECU	electronic control unit
FBCB2	Force XXI Battle, Command, Brigade, and Below
FUPP	full-up power pack
GCSS-A	Global Combat Support System Army
GRC	General Research Corporation
HNB	hull network box
IETM	interactive electronic technical manual
LCD	liquid crystal display
NEOFF	no evidence of failure
OC&S	Ordnance Center and School
PM	Program Manager
PM-TMDE	Program Manager for Test, Measurement, and Diagnostic Equipment

RPSTL	repair parts and special tools list
SINCGARS	Single-Channel, Ground and Airborne Radio System
TED	Turbine Engine Diagnostics
TOC	tactical operations center
TRADOC	Training and Doctrine Command
VGA	video graphics adapter
XML	Extensible Markup Language

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